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(71)(72) Applicant and Inventor: MADDEN, Stephen, Keith [AU/AU]; 29 Summit Drive, Devon Hills, TAS 7300 (AU).

(74) Agent: A. TATLOCK & ASSOCIATES; 21 Queensberry Street, Carlton, VIC 3053 (AU).

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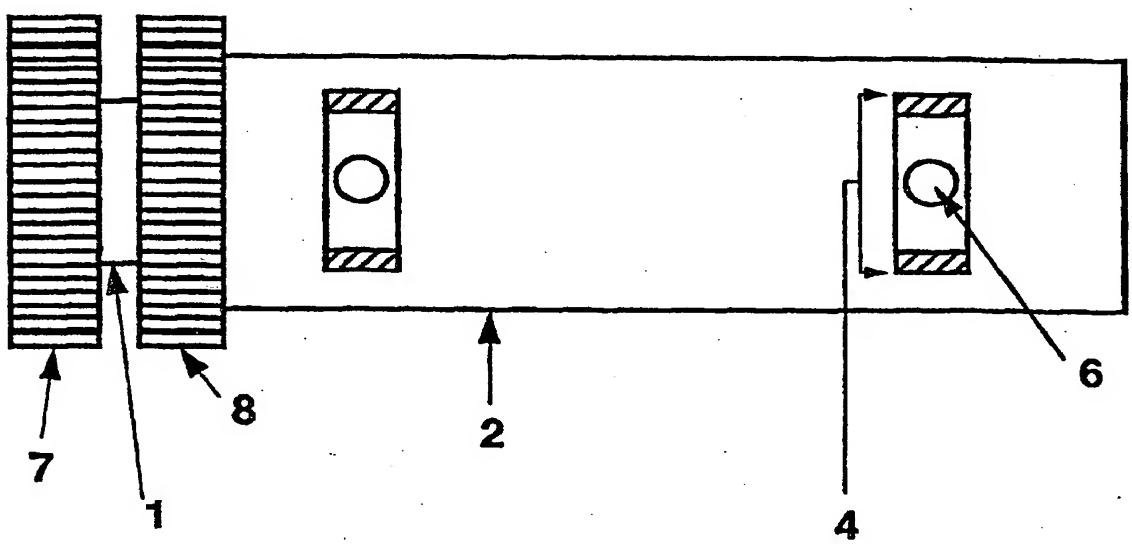

(57) Abstract

A variable timing camshaft has concentric shafts for mechanically varying the valve timing of internal combustion engines and motors and air compressors and motors. By altering the rotational position of the cam lobes attached to each shaft (1, 2) relative to each other, the valve timing can be varied. This may be achieved by periodically changing the length of a timing chain or belt on one side of sprockets (7, 8). Alternatively, it may be achieved by a series of interconnected cogs which effectively rotate one shaft (1, 2) with respect to the other. The degree of valve lift may also be varied. Inverted cam lobes may act via pivoted rocker arms to open and close the valves. A cam follower spring maintains the tension which is kept to a minimum by means of a spring tensioning device, hydraulic piston lifter or air valve. Alternatively, the relative height of the rocker arm pivot shaft or camshaft can be varied.

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VARIABLE TIMING CAMSHAFT WITH VARIABLE VALVE LIFT

This invention relates to a variable timing camshaft consisting of concentric shafts, which is used for mechanically varying the valve timing for internal combustion engines and motors and air compressors and motors. Unlike standard, non variable timing camshafts, this invention is able to take account of the engine speed, throttle position, ambient temperature, operation temperature, super charging or natural aspiration and similar parameters to ensure maximum intake turbulence occurs at all engine speeds and that the maximum possible volume of air/fuel is induced at full throttle for any engine speed. Because the invention provides for no valve overlap at low engine speeds and increasing valve overlap as the engine speed increases, mixing of inlet and exhaust gases, and expulsion of unburnt fuel through the exhaust at low speed are prevented. Also maximum valve dwell is achieved at high speed.

These features are enhanced when variable valve lift is also provided for, resulting in improved motor performance, flat torque curve from idle to maximum engine speed with near maximum torque available from minimum engine speed, improved efficiency and fuel economy, decreased pollution and smaller motor sizes with less gear changes.

When the present invention is used in a motor vehicle fitted with an air compressor and motor, in addition to the internal combustion motor, and where the air compressor is used to store compressed air directly from braking energy, and both compressor and combustion motors have valve timings varied by the invention, there exist significant advantages including no need for a starter motor, requirement for only a small battery, compressed air available to supercharge the motor or drive the compressor, reduced vehicle weight and more efficient running with its inherent benefits.

In its broadest form the present invention is a camshaft for an internal combustion engine or an air compressor or air motor, consisting of two concentrically located shafts, the second shaft located within the hollow first shaft so that both shafts are free to rotate independently of each other, with each shaft having fixed to it cam lobes such that lobes from different shafts are adjacent and capable of engaging a single valve of the engine to open and close it in response to the rotation of the shaft through one revolution, together with a means whereby the relative rotational positions of the cam lobes on the primary outer shaft and the cam lobes on the secondary inner shaft can be varied with respect to each other, thus altering the relative timing of valve opening and closing.

In order that the invention may be more easily understood

show:-

Figure 1 Concentric variable timing camshaft with slots through which primary lobes are attached;

Figure 2 Cross sectional view showing cam lobes and their attatchment to shafts;

Figure 3 Idler sprockets for varying timing chain length;

Figure 4 Timing adjustment pulley for varying timing chain length;

Figure 5 Camshaft with segmented outer shaft driven by separate drive shaft;

Figure 6 Segmented camshaft with outer cam lobes connected together;

Figure 7 Inverted cam lobe with a means of operating valves;

Figure 8 Cam follower spring tensioning device;

Figure 9 Sun, pinion and ring gears for directly varying timing;

Figure 10 Hydraulic drive for adjusting ring gears;

Figure 11 Meshed planetary gears for varying timing;

Figure 12 Means of adjusting timing by levering the planetary gears;

Figure 13 Valve lift limiting mechanism comprising valve lift limiting arm operated by valve lift limiting camshaft, and multi roller cam follower;

Figure 14 Valve lift limiting arm operated by threaded member;

Figure 15 Compression/decompression valve for air compressor or air motor;

Figure 16 Compressor output volume control device;

Figure 17 Staged hydraulic piston lifter, used to accurately vary hydraulic piston lift independently of hydraulic pressure and output volume;

Figure 18 Variable height camshaft where the cam follower acts directly on the valve stem, and also incorporating a pivoted follower and fixed arm for gentle valve closing;

Figure 19 Height adjustable rocker arm pivot shaft showing concentric eccentric cylinders used to vary height;

Figure 20 Height adjustable rocker arm pivot shaft showing vertical guide rods to prevent horizontal movement;

Figure 21 Height adjustable rocker arm pivot shaft showing threaded member height adjuster.

In one embodiment of the invention, referring to Figs. 1 & 2, the multi valve mechanically operated variable timing camshaft consists of an inner, secondary shaft 1 of metal or other suitable material and fixed at both ends to bearings or similar means so that it is free to rotate. The secondary shaft passes through the centre of the primary shaft 2 which is a cylinder and is also held at both ends but is free to

rotate independently of the secondary shaft. The primary cam lobes 3 are fixed to the primary shaft at the appropriate locations by locating pins. Immediately next to the primary cam lobe is a slit 4 passing part way around the primary shaft. The secondary cam lobe 5 fits over the primary shaft and the diameter of the hole in it is such that it can rotate freely around the primary shaft. The secondary lobe is connected to the secondary shaft by a locating pin 6 which passes through the narrow portion of the lobe, through the slit in the primary shaft and firmly attaches to the secondary shaft. By this means the secondary shaft and lobe can rotate back and forth with respect to the primary shaft and lobe, to the extent that the slit will allow.

At the end of each shaft is a sprocket or pulley 7,8. Referring to Figs. 3 & 4, they are attached to the drive shaft by a crank shaft sprocket or pulley 9 via a timing chain or belt 10. The rotation of the primary and secondary shafts are varied relative to each other, thus allowing the relative positions of the primary and secondary lobes to be varied, by means of varying the length of the chain or belt on one side of the sprockets or pulleys compared to the other. Hence when the crank is turning at constant speed a lengthening of the chain on the drive side will retard the shaft. This can be achieved by idler sprockets 11 which rotate on a carrier 12 which also rotates, to wind and unwind the chain or belt, or by way of a timing adjustment pulley 13 which, by moving in a

horizontal direction compared to the vertical chain or belt, can vary its length. Chain tension is maintained by a tensioner 14.

Thus by adjusting the relative lengthening and shortening of the chain or belt for each shaft the valve timing can be adjusted to suit the conditions.

When both lobes control the same valve, minimum valve opening time is achieved when both primary and secondary lobes are aligned and maximum valve opening time is achieved when the lobes are at the greatest possible mal-alignment.

In a second embodiment, referring to Fig. 5, the outer primary shaft 2 is a series of segments with a lobe at each end. These segments fit between the lobes turned by the inner secondary shaft. Each segment is connected by gearing or other means 15 to a separate drive shaft 16 which runs parallel with it. The drive shaft is connected to the crank shaft by means of a timing chain or belt which can be varied in length as described above for the single piece primary shaft.

In a third embodiment, referring to Fig. 6, the outer primary shaft consists of segments with lobes at each end and which fit between the lobes of the secondary shaft, but in which the primary lobes at the end of each segment are

strongly coupled together in such a way that the coupling does not interfer with the relative movement of the intervening secondary lobe, such as by a connecting piece 17 that fits into a cut-out in either the leading or trailing edge of the primary lobe.

In this embodiment no separate drive shaft is required because all segments can be driven from the sprocket at the end segment as is the case with the first embodiment described above.

To provide even greater variability in timing, referring to Fig. 7, the camshaft as described can be fitted with inverted cam lobes 18 which operate in the reverse mode to conventional cam lobes in that they open the valves when the radial distance from the edge face of the lobe to the centre of the shaft decreases and close the valves when the radial distance increases. These lobes can be attached to the concentric shafts as described above but require a lever or rocker arm 19 and pivot 20 arrangement to link the lobes to the valves 21.

Valve springs 22 close and keep closed the valves. The cam follower 23 maintains contact with the cam lobe due to the pressure exerted by the cam follower spring 24 which is stronger than the valve spring. The valve springs need only exert a fraction of the pressure exerted by conventional valve

return springs, due to their only having to combat the inertia of the valves and not the rocker arms also.

The inverted cam lobe configuration using a spring tensioned cam follower is only suitable for use with the inlet valves because of the high initial pressure of the exhaust valves.

Since there is no direct mechanical linkage between the lobes and the valves, the valve lift, and hence the degree to which the valves are opened, can be varied by using a means to limit the rocker arm movement.

The rocker arms can be limited in their movement, and hence the degree of valve opening limited, by a number of means which include valve lift limiting cam lobes 25 which simply by turning limit the movement. They can be located on the main camshaft or a separate camshaft. The lift limiting cam lobes can operate together or independently of each other. They would be situated and have their timing set so as to contact the rocker arms when valve opening is to be limited. The movement of the valve lift limiting cam lobe is such that at one extreme it prevents the valves from opening, while at the other extreme the effective cam profile is followed in its entirety.

In another embodiment in Figs. 13 & 14, instead of the valve lift limiting cam lobe acting directly on the rocker arm, a

lift limiting arm 58 is used. This lift limiting arm is varied in height by either a lift limiting cam lobe 60, or a threaded shaft 70. The lift limiting arm is used in conjunction with pivoted cam follower 57 which may include multiple rollers. The purpose of the pivoted cam follower is to enable a smooth decrease and increase in speed of the rocker arm when movement is limited by the lift limiting arm.

In order to maintain high valve lift at high engine revolutions considerably more tension is required from the cam follower spring than is required at low engine revolutions with low valve lift. In order to reduce frictional losses and wear, and increase the operating life time, the spring tension can be varied dynamically to the minimum required for the particular operating conditions.

The invention includes three possible means of varying the follower spring tension. In the first means, referring to Fig. 8, the spring 24 has a collar 25a fixed to one end, through which a threaded member 26 passes so that when the head of the member 27 is held against a fixed bearing surface and it is rotated, for example by a worm screw 28 driven either individually or in combination with those on other springs, by an electric servo motor, the collar moves up or down thus increasing or decreasing the spring tension. The rocker arm acts via the spring from the fixed bearing point.

A second means of varying the spring tension is by use of a pneumatic spring where air under pressure provides the tension and where the air pressure can be increased or decreased to vary the effective spring tension, the pneumatic spring is connected to an air receiver enabling near constant spring tension for the full length of the travel thus exerting less force on the rocker arm with the valve closed. This results in the minimum required contact pressure between the cam follower and the cam lobe for all operating conditions.

Fig. 17 shows a third means for varying the tension whereby a staged hydraulic piston lifter provides a means to accurately move a device with hydraulic assistance. It operates over a wide range of hydraulic pressure and maintains accuracy of positioning for this pressure range and also for a large range of hydraulic fluid through-put volume.

The staged hydraulic piston lifter consists of a piston 75, which has a series of spiral holes 77, commencing half way down and continuing to the bottom of the cylinder. The piston is turned in the cylinder 76, by a sliding cog 81 or similar means. In the top of the cylinder on the inside a vertical slit 78 is cut. This slit is connected to an opening 80 which is connected to an oil return line. Oil enters the cylinder under pressure via the oil gallery 79, the oil forces the piston upwards until one of the holes in the side of the piston is uncovered by the slit, oil now passes through this

hole and through the slit to emerge through the oil return line, preventing further upwards movement of the piston. The piston remains at this set height no matter what volume or pressure of oil enters the cylinder (within reason), and also providing that the pressure applied to the top of the cylinder does not exceed the total upwards pressure. Turning the piston in the cylinder results in the original aligned hole being closed. One of the two things may happen. First, if the next hole to be aligned with the slit is below the slit, oil pressure will move the piston up until that hole is uncovered, at which point the piston will stop moving. Secondly, if the next hole to align with the slit is part way up the slit, oil will be forced out of that hole through the slit (due to any force applied to the top of the piston) causing the piston to fall, until that hole is just uncovered enough to allow the input volume of oil to pass through.

Figures 19, 20 and 21 show another variable valve lift and timing arrangement in which the rocker arm pivot shaft passes through a series of pivot shaft supports. The pivot shaft 61 passes through an eccentric centred circular lobe 62 to which it is directly attached, this lobe is positioned within another eccentric circular lobe 63, but is separated from that lobe by a bushing or bearing so that it is free to move within the lobe. This outer eccentric lobe is positioned within the shaft support 64, and separated from the support by another bearing or bushing. The shaft support also includes

guide rods or bars 65, in which slides the shaft positioner 66, which determine the direction of movement of the pivot shaft. By turning the pivot shaft the shaft rises or falls within the shaft supports, which moves the cam followers further from the cam lobes by a factor of double the pivot shafts vertical movement.

This same effect can also be achieved by using a threaded shaft 67, attached to the shaft positioner from above and passing through a threaded rigid section 68. This threaded shaft has a cog or pulley 69 on top and a means of individually or synchronously turning with the other pivot shaft adjustors.

The staged hydraulic piston lifter described previously may also be used to vary the height of the pivot shaft supports.

In order to maintain contact between the cam lobe and cam follower and also the rocker arm and the valve when the rocker arm pivot point is raised, the valve lift limiting arm previously described for use with inverted cam lobes is used to limit the downwards movement of the cam follower. The valve lift limiting arm in this case can be held in contact with the cam follower with the valve seated by use of a device similar to a conventional hydraulic valve lifter. A pivoted cam follower, which may incorporate multi rollers (i.e. a triangular triple roller) is also used with this setup to

facilitate gentle valve closing.

To incorporate variable valve limiting and lift in a twin overhead cam motor where the cam follower directly acts on the valve stem without the use of rocker arms the following configuration is used: Firstly the camshaft itself is moved up and down in a similar fashion to the techniques described for varying the height of the rocker arm pivot point (Figs.19-21). Drive to the camshafts is provided by the two idler cogs as described in the fifth embodiment of the invention, which allows movement of the camshaft relative to the drive sprocket as well as variation of the phase angle of the camshaft.

In this embodiment, referring to Fig 18, the cam followers 40 operate up and down in a guide 41 concentric with the valve stem, the cam contact section of the cam follower 53 is pivoted in a similar fashion to that described previously, in this case however, to provide smooth valve closing, a fixed arm 39 is provided both sides of the cam lobes 3,5 and positioned at the right height above the cam follower to just clear the follower with the valves fully closed. One side of the pivoted follower contacts these arms just before the valve closing point which results in the movement of the cam follower slowing by comparison to following the cam profile directly, ensuring gentle valve seating. The pivoted cam follower is essential for when limited valve lift is employed, due to the steep closing face of the cam lobe which could be

encountered. This arrangement requires no valve lift limiting arms or hydraulic valve lifter type devices as required with the moveable pivot point arrangement.

The above arrangement can be used for both inlet and exhaust valves with conventional cam profiles, and offers fully variable valve lift, and by reason of the profile of conventional cam lobes, also offers variable valve dwell and timing directly related to the valve lift. By using a camshaft advance, retard (phasing) mechanism the timing can also be varied, and by using a multiple lobe concentric camshaft, fully variable valve timing and lift can be achieved.

The profile of the exhaust and inlet cam lobes can vary on their opening and closing faces to change the relative advance and retard to each other for various degrees of valve lift, this feature is particularly useful when a variable timing single camshaft is used. The threaded shaft or staged hydraulic piston lifter operated rocker pivot shaft adjustors are particularly suited for individually varying the valve lift.

Using the variable valve lift feature for all valves in certain cylinders, the rocker arms could be disengaged for those cylinders, effectively disengaging those cylinders. This feature is particularly useful for low speed, low

throttle operating conditions, where pumping losses and valve train frictional losses can account for a large proportion of the total energy drain on the motor. These forms of energy loss do not occur in cylinders with the valves deactivated. Also with the larger volume of combustion mixture entering the active cylinders, less pumping energy losses occur in those cylinders.

In a fourth embodiment of the invention, referring to Fig. 9, the cam drive sprocket 7 is driven directly from the crank sprocket. The cam drive sprocket turns the pinion carrier 29 which has two sets of pinion gears 30 free to turn in the pinion carrier. The pinions are engaged to the valve timing ring gears 31. These are held stationary and hence the pinions tend to "walk" around the ring gear and as they do so turn sun gears. One sun gear 32 turns the primary shaft while a second 33 turns the secondary shaft.

Control of valve timing is achieved by adjusting the ring gears. The valve opening point is varied by turning the primary ring gear while the valve closing point is varied by turning the secondary ring gear. The ring gears may be turned by a worm drive run by a microprocessor controlled bi-directional electric motor which meshes with teeth on the outside of the ring gear and when unenergized holds the ring gear stationary.

Alternatively (Fig. 10) an hydraulic drive 34 can be employed using a normally closed bi-directional valve which when closed rigidly holds the ring gear but when pressure is applied in either direction the hydraulic shaft 35 is forced in or out to vary the valve timing.

In a fifth embodiment of the invention, referring to Figs. 11 & 12, the power to drive one or both of the variable timing shafts is transferred from cog 36 via two meshed idler cogs 37 attached to a carrier and situated between the driving 36 and driven 32, 33 cogs.

The drive shaft cog is not meshed directly to the driven shaft cog but via the two intermeshed smaller idler cogs which are so held that they can move to a degree around their associated cogs. Thus (Fig. 12) by moving the timing adjustment lever 38 the first idler cog rotates around the driving cog which turns the second idler cog in the opposite direction which, in turn, turns the driven cog through an angle relative to the driving cog, giving a phase angle variation.

In order to better understand the invention we shall describe the use of the invention as described in any of the preceding embodiments, to vary the timing of inlet and exhaust valves of a dual operation air compressor/air motor designed to operate a motor vehicle and supplement its internal combustion engine.

In this type of motor in the power mode, power is produced by the compressor by introducing compressed air to the cylinder, which forces the piston down thereby turning the crank shaft. The inlet/exhaust valve and optional purge valve are then opened allowing the air in the cylinder to be exhausted and reducing pressure for the upstroke.

Use of the variable timing camshaft makes it possible to make full and the most efficient use of the compressed air. This is achieved by use of a compression/decompression valve attached to each compressor cylinder. Referring to Fig. 15, this valve consists of a valve body 42 with a passage at one end 43 passing into the compressor cylinder, a valve plunger 44 which passes through an air tight passage 45 at the other end of the body and capable of sealing the passage way into the compressor cylinder when forced against it, a valve guide 46 through which air can flow and a valve guide stop 47 which limits movement of the valve body, and a passage way 48 from the inside of the valve body to a high pressure air receiver.

The extensions of the plunger arm protruding from the body is connected via a solenoid 49 and valve return spring 50 to a brake slave cylinder 51 which is in turn connected to the brake master cylinder via the compressor output volume control device. Concentric with and inside the valve return spring is a brake control spring 52.

In the power mode, the solenoid operating the compression/decompression valve is briefly energised at t.d.c. and remains open until the valve is energised in the reverse direction. Compressed air then passes through the valve from the receiver into the cylinder to propel the piston on its downward stroke. The valve is then closed by energising the solenoid in the reverse direction. The timing of the closure depends on the power requirements of the system and the pressure of stored compressed air.

The main purpose of the compressor as a power source is to bring the vehicle up to sufficient speed from stationary to cut in the combustion motor thus replacing the starter motor and making it feasible to turn off a combustion motor when stopped at traffic lights and still have maximum torque available for instant take off, and to provide low speed high torque power to improve traction. As soon as the throttle is touched, compressed air enters the compressor cylinder with piston nearest to t.d.c. forcing it down and commencing rotation of the compressor crank. The clutch is then engaged enabling the power from the compressor to turn the motor and start it. The compressor motor can remain engaged providing power from both the motor and compressor until the combustion motor speed rises sufficiently or while the compressor is required to build up compressed air reserves.

The main use of the compressed air is for supercharging the

combustion motor by direct injection into the cylinders of the motor after the air intake valve closes but before ignition point, to achieve maximum air/fuel charge for the minimum volume of compressed air used.

In the power mode the variable timing camshaft is used to operate the poppet valve acting as an exhaust valve. The secondary shaft opens the exhaust valve, the timing of which is dependent or the volume of air injected, the valve commences to open when the pressure of the compressed air in the cylinder has been reduced to atmospheric or b.d.c. reached. The primary shaft is used to close the exhaust valve.

The compressor mode, in which air is forced into the air receiver for storage, is entered when the vehicle brakes are applied, at which time the compressor is engaged thus transforming the kinetic energy which is normally lost as heat in the braking system into potential energy by way of stored compressed air. Braking with the compressor is achieved in two ways, (a) by varying the volume compressed, and (b) by varying the pressure, and is determined by the amount of braking effort required and the pressure of air currently stored in the air receiver.

In the compressor mode the primary cam lobe is timed to commence opening the inlet valve just past t.d.c. The timing

for the secondary cam lobe can be varied to fully close the inlet valve anywhere between b.d.c. and just before t.d.c., depending on brake pressure and air receiver pressure.

Fig. 16 shows how this is achieved by using a double acting cylinder, one side 71 is connected to compressed air from the receiver and the other 72 to the hydraulic brake master cylinder. A lever is attached to the connecting rod 73 which varies the phase angle of the secondary shaft so as to advance or retard the secondary shaft. A spring is incorporated in the hydraulic brake fluid side of the double acting cylinder, to ensure that the valve closing occurs at b.d.c. when minimal pressure is present in the receiver. This ensures that the maximum volume of air is compressed when there is the minimum resistance to air flow.

With the brake piston at full travel hydraulic fluid can act on the slave cylinder 51 of the compression/decompression valve. The fluid is returned by a one way return valve 74 when the brakes are released.

As air pressure builds up the piston moves against the hydraulic fluid and spring pressures and alters the secondary shaft timing, to close as late as just prior to t.d.c. hence reducing the volume of air compressed whilst maintaining the same braking effort. More brake pressure will progressively alter the closing point until closing occurs by b.d.c.

Hydraulic fluid provides increasing pressure to the base of the compression/decompression valve to increase the air pressure required to lift the valve body from its seat.

It should be noted that when changing from compressor mode to power mode the valve timing is always retarded and when changing from power to compressor mode the valve timing is always advanced. This is to allow changes at any time without risk of the valve striking the piston.

A multi-function clutch assembly is used to connect the engine to the drive-train, the compressor to the drive-train, or to interconnect the engine, compressor and drive-train.

Claims:

1. A camshaft for an internal combustion engine or an air compressor or air motor, consisting of two concentrically located shafts, the second shaft located within the hollow first shaft so that both shafts are free to rotate independently of each other, with each shaft having fixed to it cam lobes such that lobes from different shafts are adjacent and capable of engaging a single valve of the engine to open and close it in response to the rotation of the shaft through one revolution, together with a means whereby the relative rotational positions of the cam lobes on the primary outer shaft and the cam lobes on the secondary inner shaft can be varied with respect to each other, thus altering the relative timing of valve opening and closing.

2. A camshaft as claimed in claim 1 where the outer primary shaft has slots cut in it to allow the keys holding the secondary cam lobes to pass through and attach to the secondary shaft and the slots being of such length to allow the outer primary shaft to partially rotate about the inner secondary shaft.

3. A camshaft as claimed in claim 1 having an outer primary shaft consisting of segments with a cam lobe at each end and which segments fit between the cam lobes attached to the inner secondary shaft so that each segment is free

to rotate about the secondary shaft, and where each segment is connected to a single drive shaft that runs parallel to the camshaft by a means which allows the drive shaft to turn the primary shaft.

4. A camshaft as claimed in claim 3 in which the outer primary cam lobes of adjoining segments are solidly joined together in such a way as to allow the primary and secondary cam lobes to move relative to each other.

5. A camshaft as claimed in claim 4 in which the inner camshaft turns the leading cam lobe while the outer shaft turns the trailing cam lobe, and in which the piece connecting the cam lobes from neighbouring outer shaft segments fit into cut out segments from the trailing edge of the lobe driven by the inner shaft thus allowing the lobes to move in relation to each other.

6. A camshaft as claimed in any preceding claim where the cam lobes function in an inverted fashion so that the valves are fully open when the cam follower contacts the narrowest point of the lobe and fully closed when contacting the broadest point of the lobe.

7. A camshaft as claimed in claim 6 in which the opening of the valves is achieved by a lever or rocker arm connecting between the cam lobe, through a cam follower,

and the valve and pivotting between them and in which a cam follower spring is used to provide tension to hold the cam follower against the cam lobe.

8. A camshaft as claimed in claim 6 in which the opening of the valves is achieved by a lever or rocker arm which is pivoted at one end and transfers movement between the cam lobe and the valve at the other end.

9. A camshaft as claimed in either claim 7 or 8 in which the cam follower spring has a means of varying its tension.

10. A camshaft as claimed in claim 9 in which the means of varying spring tension consists of a supported threaded member engaging through a threaded hole in a collar attached to the top of the spring so that by turning the member the collar moves up or down and hence releases or compresses the spring, and which turning of said member is achieved by means of a worm drive cog, belt, chain or other type of cog drive.

11. A camshaft as claimed in claim 9 in which the means of varying spring tension consists of a staged hydraulic piston lifter in which the piston has a series of spiral holes which align in sequence with a slot cut in the cylinder and which is connected to the low pressure oil line, when sufficient movement of the piston has occurred

so that turning the piston varies the travel.

12. A camshaft as claimed in claim 9 in which the cam follower spring is a pneumatic spring controlled by means of a variable pressure air reservoir.

13. A camshaft as claimed in claim 12 in which pneumatic springs are attached to more than one valve and which springs are all connected to the same reservoir hence unifying control of multiple valves.

14. A camshaft as claimed in any of claims 7 to 13 in which the valve lift is varied by controlling the movement of the rocker arm.

15. A camshaft as claimed in claim 14 in which movement of the rocker arm is regulated by a separate valve lift limiting camshaft and cam lobe that engages the rocker arm.

16. A camshaft as claimed in claim 14 in which a lift limiting arm is used to limit the movement of the cam follower and such that the lift limiting arm is controlled by any of the control mechanisms of claims 10, 11 or 15.

17. A camshaft as claimed in claim 16 in which the rocker arm

utilizes a pivoting cam follower which may have multiple rollers which enable a smooth increase or decrease in speed of the rocker arm when its movement is arrested by the lift limiting arm.

18. A camshaft as claimed in any preceding claim where the camshaft is connected to the drive shaft by means of a timing chain or belt and in which the relative timing of the two shafts is varied by using means which periodically differentially increase the length of chain or belt connecting one side of the camshaft to the drive shaft thus causing a relative advance or retard of the camshaft rotation compared to that of the drive shaft rotation.

19. A camshaft as claimed in claim 18 in which the relative lengths of the timing chain or belt are varied by means of idler sprockets on carriers capable of pivotting, on each side, which alternately wind and unwind part of the belt or chain.

20. A camshaft as claimed in claim 18 in which the length of chain or belt on one side is varied by means of a timing adjustment pulley which moves in and out, while a spring loaded idler pulley maintains the tension on the other side.

21. A camshaft as claimed in any of claims 1 to 17 in which the cam drive sprocket is connected directly to a pinion carrier containing two sets of pinion gears, with each set of pinion gears meshed to a separate ring gear and sun gear, where one sun gear turns the primary camshaft and the other turns the secondary camshaft, so that by turning either ring gear the phase angle of the corresponding shaft changes.

22. A camshaft as claimed in claim 21 in which the ring gears are adjusted by an lever the length of which is varied by an hydraulic drive.

23. A camshaft as claimed in claim 21 in which the ring gears are rotated by mean of a worm drive which meshes with teeth on the ring gear.

24. A camshaft as claimed in any of claims 1 to 17 in which the cam drive cogs on both the inner and outer shafts are connected to a similar drive cog turned by the camshaft drive sprocket, by way of two smaller planetary idler cogs that are held so as to mesh with each other and one meshing with the drive cog and the other with the driven cog but so that the drive and the driven cogs do not mesh, and so that by levering the planetary cogs to change their position relative to the shaft cogs the relative rotations of the shafts can be varied in

comparison to each other.

25. A camshaft as claimed in any of claims 1 to 17 in which the outer shaft is moved relative to the inner shaft by a hydraulic means where the hydraulic cylinder is attached to the inner shaft and the piston is a hollow tube passing around the inner shaft and inside an extension of the outer shaft and which piston is connected by splined sliding gears to each shaft so that when the piston moves it rotates the shafts relative to each other.

26. A means to vary valve timing and valve lift by altering the height of the rocker arm pivot or the camshaft comprising means associated with the pivot or shaft so that it can rise and fall along its length whilst remaining fully supported.

27. A means to vary valve timing and valve lift as described in claim 26 using circular eccentric lobes, and whereby rotating the pivot shaft, it rises or falls along its entire length whilst remaining fully supported for its entire length.

28. A means to vary valve timing and valve lift as claimed in claim 26 in which the means to vary the height of the rocker arm pivot point consists of using a threaded member engaging through a threaded hole in the top of the

rocker arm shaft support guide engaging the rocker arm support so that by turning the member the rocker arm support moves up or down and hence raises or lowers the rocker arm height.

29. A means to vary valve timing and valve lift as claimed in claim 26 in which the means to vary the height of the rocker arm pivot point consists of using a staged hydraulic piston lifter in which the piston has a series of spiral holes which align in sequence with a slot cut in the cylinder and which is connected to the low pressure oil line, when sufficient movement of the piston has occurred so that turning the piston varies the travel, and so that by turning the piston the rocker arm support moves up or down and hence raises or lowers the rocker arm height.

30. A means to vary valve timing and valve lift as claimed in any of claims 26 to 29 and to provide gentle closing of valves and remove rocker arm free play, in which the rocker arm utilises a pivoting cam follower to enable a smooth increase or decrease in speed of the rocker arm when its movement is arrested by arms on both sides of the cam lobes which are raised by a conventional hydraulic valve lifter to sufficient height to contact the cam follower with the valve seated.

31. A means to vary valve timing and valve lift as claimed in any of claims 26 to 29 which has a camshaft where the cam lobes act directly through cam followers to the valves and where the height of the camshaft above the valves can be varied to vary valve timing, dwell and lift, and incorporating a pivoting cam follower and fixed height arm to facilitate gentle valve closing.

32. A means to vary valve timing and valve lift as claimed in claim 31 where the opening and closing points of the inlet and exhaust valves can vary with respect to each other but are fixed for a particular valve lift.

33. A means to vary valve timing and valve lift as claimed in claim 32 in which varying the opening and closing points of the inlet and exhaust valves is achieved by cam lobes with opening and closing faces ground to suit the valve timing required for that degree of valve lift, which is in turn varied to suit the engine operating conditions.

34. An air compressor or air motor in which the inlet/exhaust valves are controlled by a camshaft or means as claimed in any of claims 1 to 33.

35. An air compressor or air motor as claimed in claim 34 in which efficient operation is maximized by adjusting the timing in conjunction with the use of a

compression/decompression valve which utilizes the energy from braking by allowing storage of the air compressed in that mode for future use in the power mode or for supercharging.

36. A compression/ decompression valve capable of working in conjunction with a camshaft as claimed in any of claims 1 to 25 to utilize braking energy to store and release compressed air for the efficient functioning of an air compressor or air motor as claimed in claim 34.

37. A means of automatically controlling the output of a compressor as claimed in claims 34 to 36.

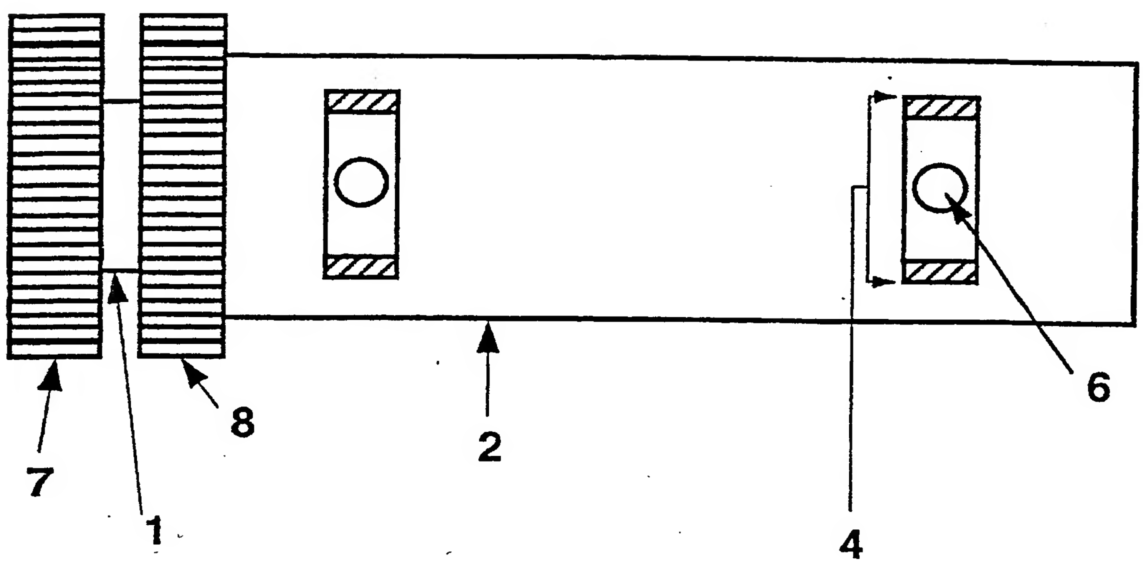

Fig. 1

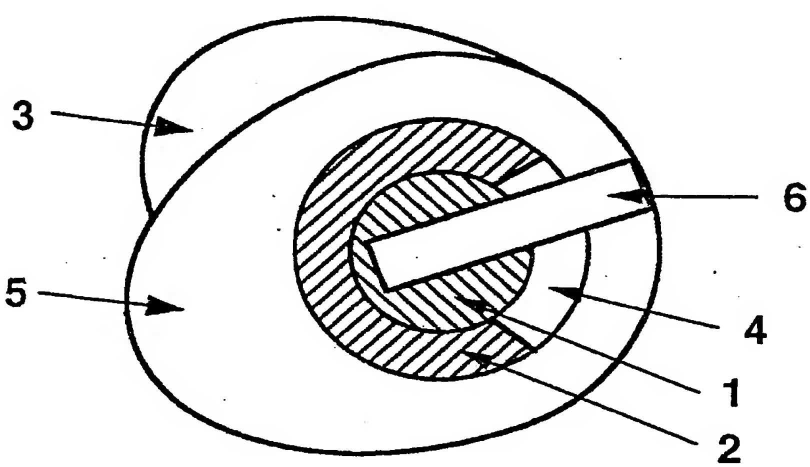

FIG 2

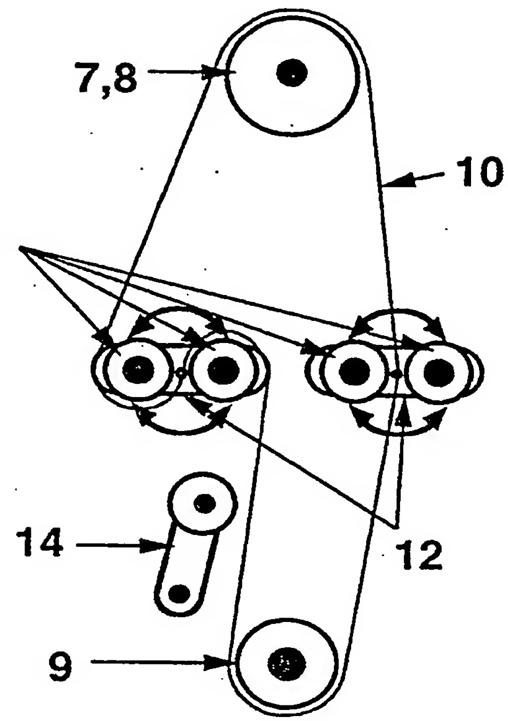

FIG 3

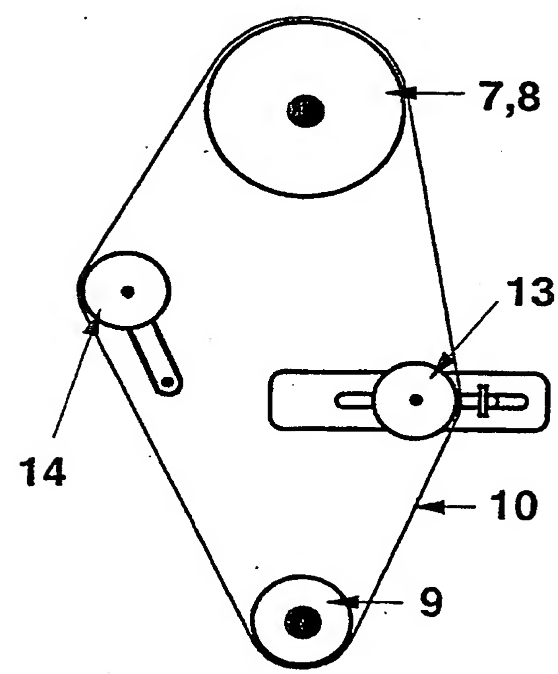

FIG 4

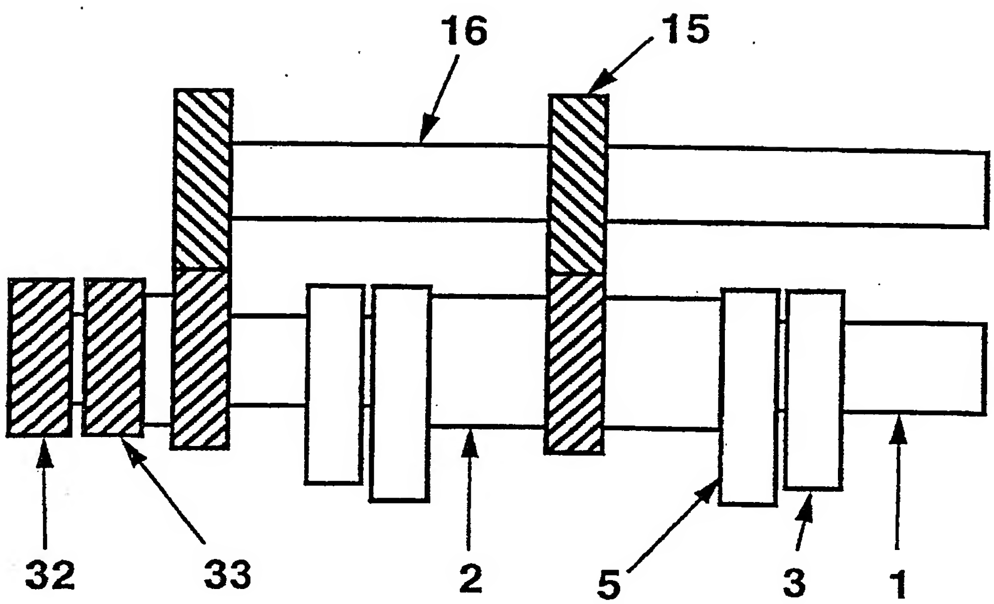

FIG 5

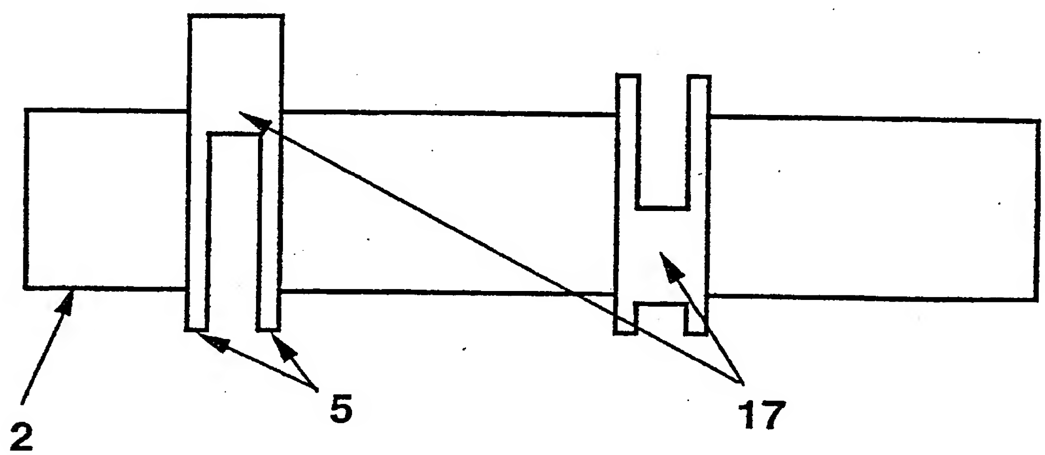

FIG 6

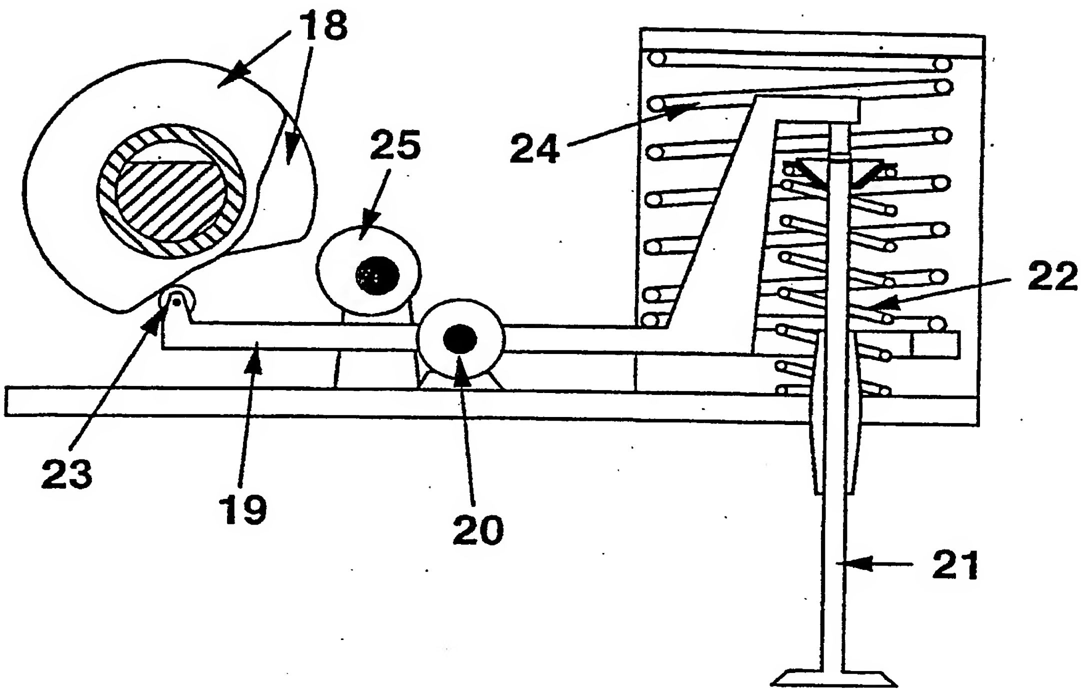

FIG 7

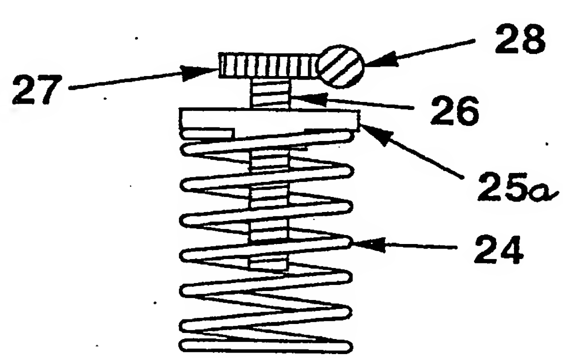

FIG 8

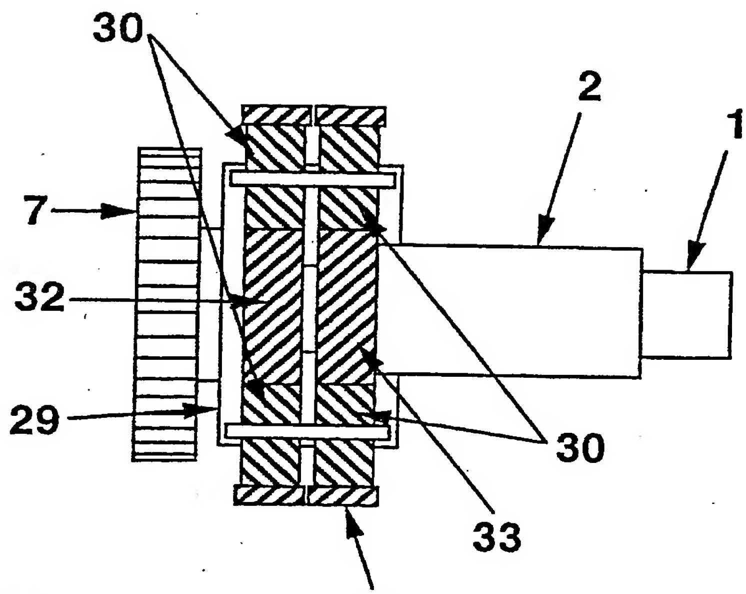

FIG 9

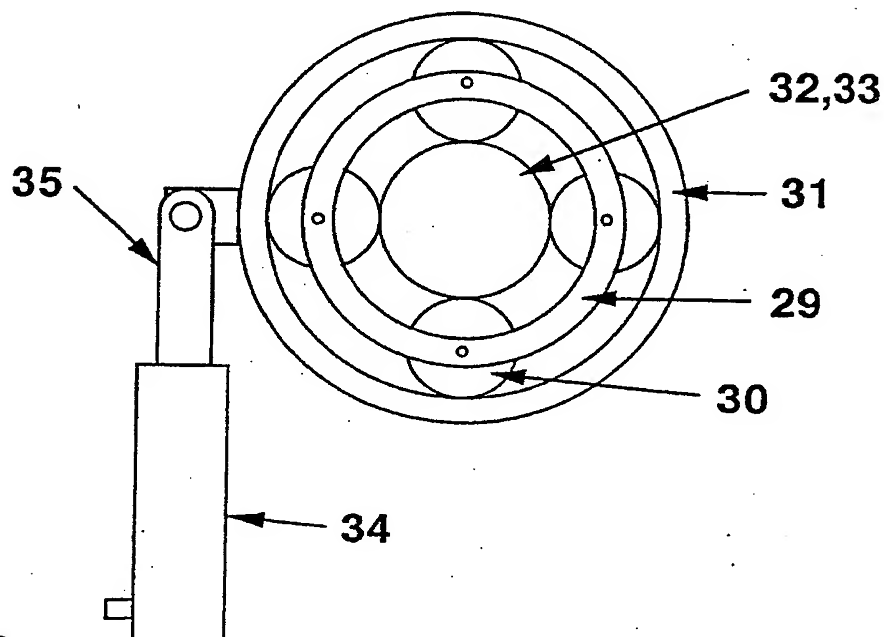

FIG 10

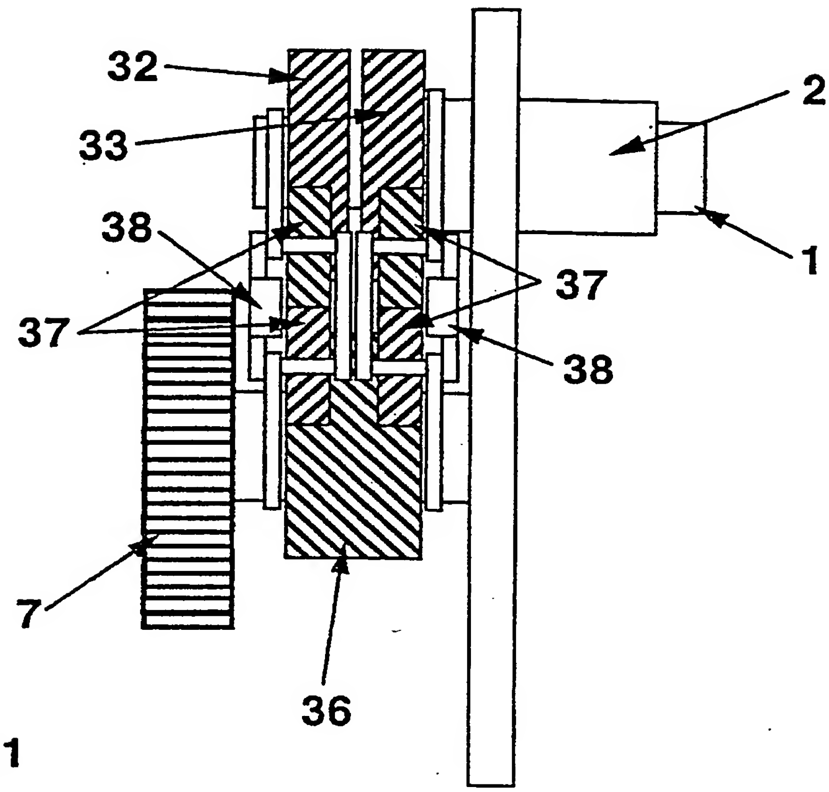

FIG 11

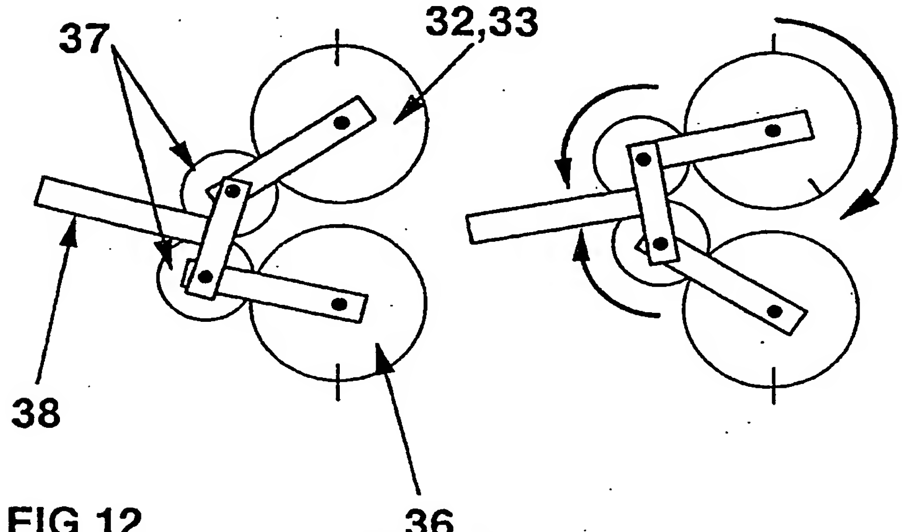

FIG 12

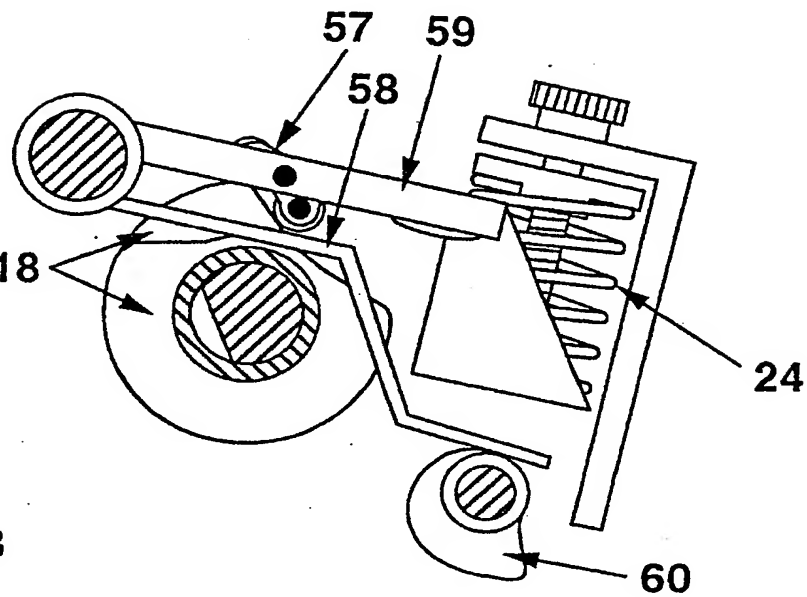

FIG 13

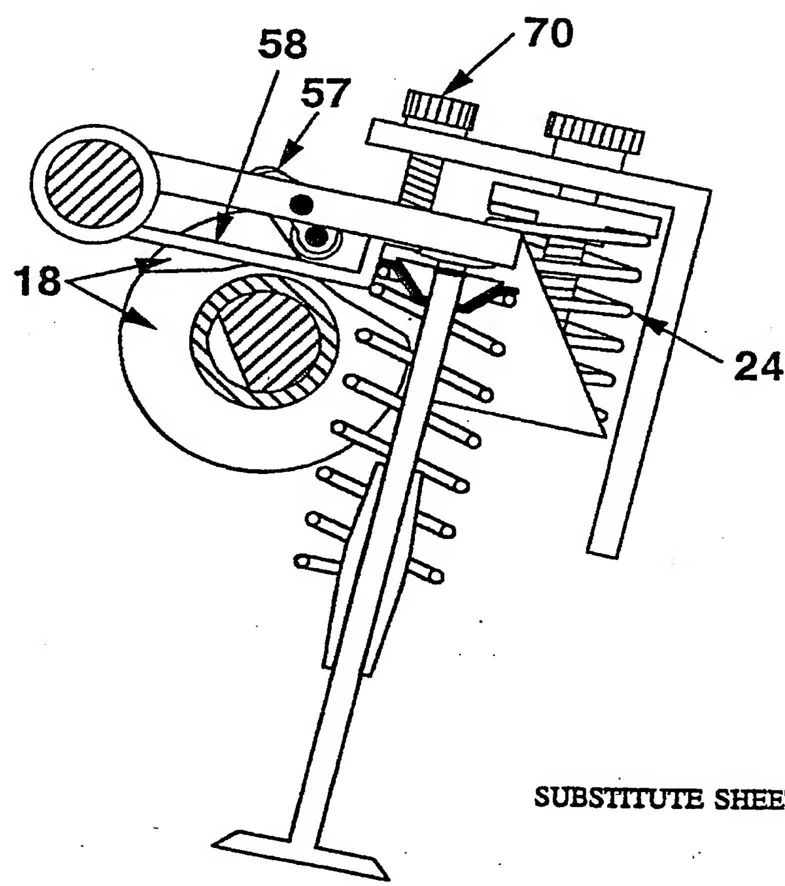

FIG 14

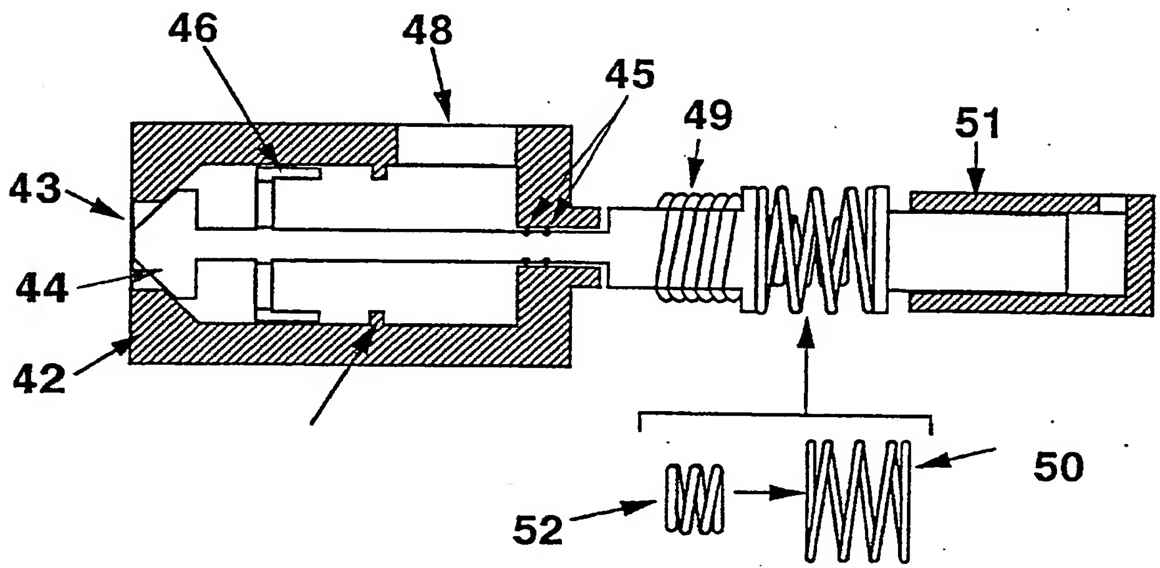

FIG 15

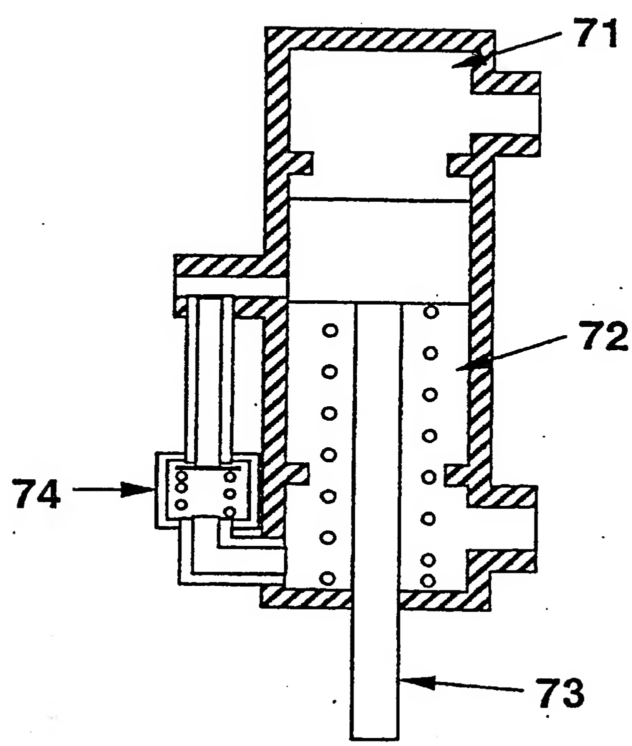

FIG 16

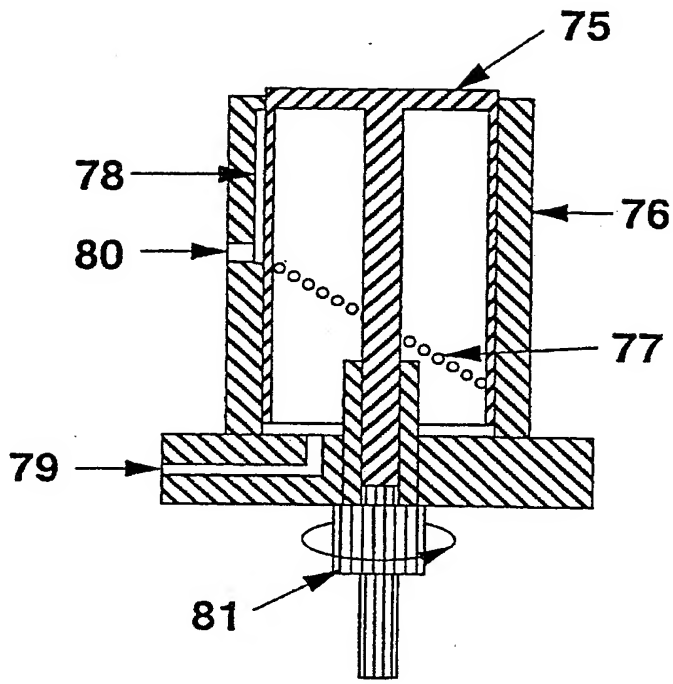

FIG 17

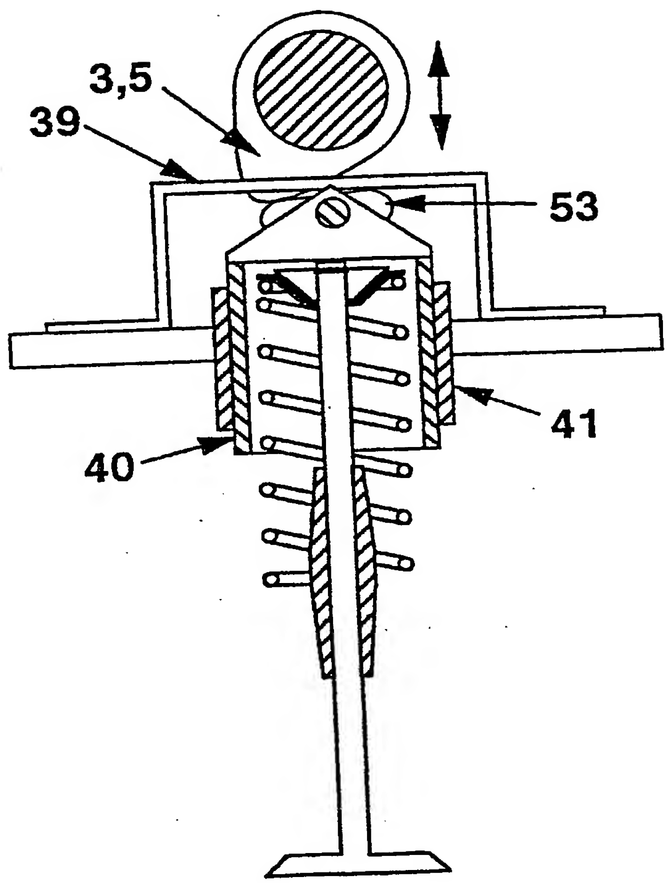

FIG 18

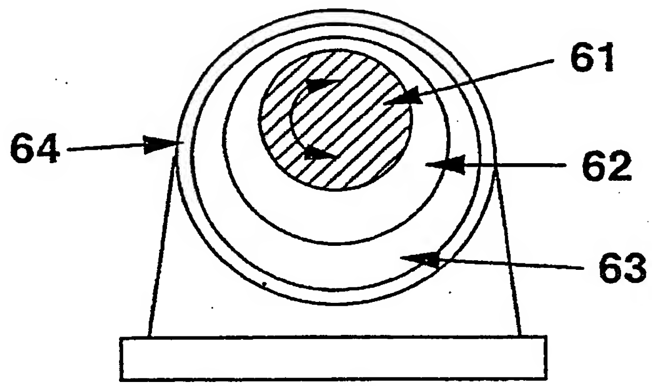

FIG19

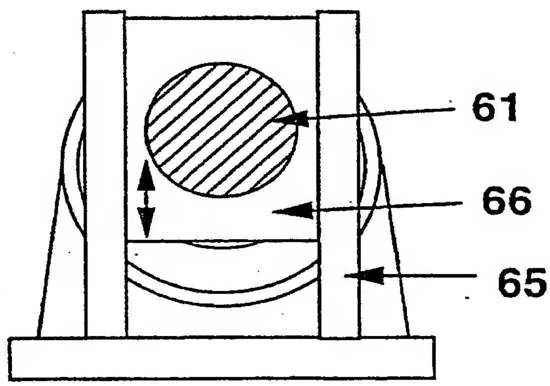

FIG 20

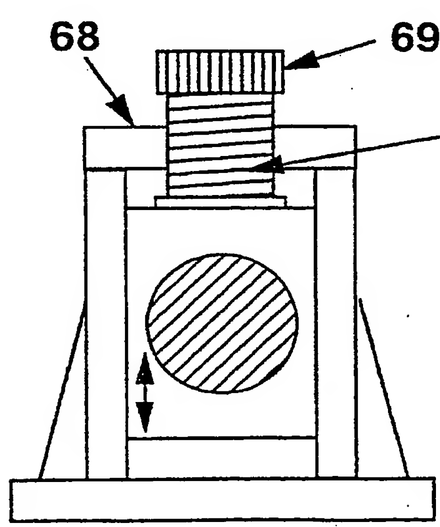

FIG 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 95/00002

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.^{6} F01L 1/04, 1/18, 1/34, F16H 53/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC : F01L 1/04, 1/18, 1/34, F16H 53/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above

Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)
DERWENT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US,A, 4771742 (NELSON et al) 20 September 1988 (20.09.88) whole document pertinent	1-2, 34, 37
X	US,A, 4517934 (PAPEZ) 21 May 1985 (21.05.85) column 4, lines 44-61 and Figs. 1 and 2	1-2, 34, 37
X	US,A, 4332222 (PAPEZ) 1 June 1982 (01.06.82) column 7, lines 20-45 and Fig. 12	1-2, 34, 37
X	DE,A, 3934848 (von INGELHEIM) 25 April 1991 (25.04.91) Fig. 1	1-2, 34, 37

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 March 1995 (31.03.95)	5 APRIL 1995 (05.04.95)
Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No. 06 2853929	Authorized officer C.M. WYATT Telephone No. (06) 2832538

C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
X	DE,A, 3212663 (MARTIN) 13 October 1983 (13.10.83) Fig. 1	1-2, 34, 37
X	US,A, 4643141 (BLEDSOE) 17 February 1987 (17.02.87) whole document pertinent	26-27, 34, 37
X	US,A, 3897760 (HISSERICH) 5 August 1975 (05.08.75) whole document pertinent	26-27, 34, 37
X	DE,A, 3615449 (SCHMID) 12 November 1987 (12.11.87) drawing figures	26-27, 34, 37
X	Patent Abstracts of Japan, M-424, page 29, JP,A, 60-113005 (SUZUKI JIDOSHA KOGYO K.K.) 19 June 1985 (19.06.85) abstract	26, 34, 37
X	Patent Abstracts of Japan, M-491, page 75, JP,A, 61-25905 (HITACHI LTD) 5 February 1986 (05.02.86) abstract	26, 34, 37

Box II (continued)

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are two inventions:

1. Claims 1-25 are directed to:

"A camshaft for an internal combustion engine or an air compressor or air motor, consisting of two concentrically located shafts, the second shaft located within the hollow first shaft so that both shafts are free to rotate independently of each other, with each shaft having fixed to it cam lobes such that lobes from different shafts are adjacent and capable of engaging a single valve of the engine to open and close it in response to the rotation of the shaft through one revolution, together with a means whereby the relative rotational positions of the cam lobes on the primary outer shaft and the cam lobes on the secondary inner shaft can be varied with respect to each other, thus altering the relative timing of valve opening and closing." The features underlined are considered as comprising a first "special technical feature".

2. Claims 26-33 are directed to:

"A means to vary valve timing and valve lift by altering the height of the rocker arm pivot or the camshaft comprising means associated with the pivot or shaft so that it can rise and fall along its length whilst remaining fully supported". The feature underlined is regarded as comprising a second "special technical feature".

Since the above-mentioned groups of claims do not share either of the technical features identified, a "technical relationship" between the inventions, as defined in PCT Rule 13.2, does not exist. Accordingly, the international application does not relate to one invention or to a single inventive concept.

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	4771742	AU	46124/89	AU	46125/89	CA	1323260
		CA	1323261	CA	1324041	EP	234853
		EP	440314	EP	596860	JP	62253912
		US	4770060	US	4917058		
US	4517934	US	4332222	DE	2930266	DE	2822147
		FR	2426152	IT	1112927		
US	4332222	DE	2822147	FR	2426152	IT	1112927
		US	4517934				

END OF ANNEX